Determination of Resting Energy Expenditure After Severe Burn

Beth A. Shields, MS, RD,* Kevin A. Doty, MS,* Kevin K. Chung, MD,* Charles E. Wade, PhD,*† James K. Aden, PhD,* Steven E. Wolf, MD*‡

The purpose of this study was to evaluate the accuracy of nine predictive equations for calculating energy expenditure in severely burned adult subjects. The selected equations have been reported as commonly used or determined to be the most accurate. This prospective, observational study was conducted on adult subjects admitted between October 2007 and July 2010 with ≥20% TBSA full-thickness burns (excluding electrical burns or severe head injury). Indirect calorimetry measurements were conducted as a convenience sample during the first 30 days after injury. Demographic data were collected, and resting energy expenditure was calculated using the nine selected predictive equations and compared to measured energy expenditure (MEE) using descriptive and comparative statistics. Data were collected on 31 subjects with an average age of 46 ± 19 years and %TBSA burn of 48 ± 21%. For all equations, slopes and intercepts were significantly different from the line of identity when compared with MEE. A calorie-dependent bias was present for all equations, in that lower calorie range was overestimated and the higher calorie range was underestimated. Only the Carlson and Milner equations had results that were not significantly different from the MEE and mean differences that were not significant in all burn size ranges. None of the equations had a strong correlation with MEE. Of the equations available, the Milner and Carlson equations are the most satisfactory in predicting resting energy expenditure in severely burned adults when indirect calorimetry is unavailable. (J Burn Care Res 2013;34:e22-e28)

In burn-induced hypermetabolism, resting energy expenditure (REE) can be elevated to twice-normal levels with increased heart rates, rates of breathing, body temperature, oxygen (O_2) consumption, carbon dioxide (CO_2) production, glucose use, glycogenolysis, lipolysis, and proteolysis.[1] Although indirect calorimetry (IC) allows for measurement of REE by determining the O_2 consumption and CO_2 production,[2] its routine use for all hospitalized burn patients is impractical and costly. Many predictive equations have been developed to estimate energy expenditure and account for the increase in metabolism after burn. However, the Society of Critical Care Medicine along with the American Society for Parenteral and Enteral Nutrition recommended in their 2009 Guidelines that predictive equations to estimate nutritional requirements be used with caution.[3] Equations normally include a limited number of factors, such as height, weight, and age; but critically ill patients have many other factors contributing

*From the *Department of Nutritional Medicine at San Antonio Military Medical Center, the United States Army Institute of Surgical Research, Fort Sam Houston, Texas; †Department of Surgery, Center for Translational Injury Research, University of Texas Health Science Center, Houston, Texas; and ‡Department of Surgery at the University of Texas Southwestern Medical Center, Dallas, Texas.*

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The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

This study was conducted under a protocol reviewed and approved by the US Army Medical Research and Material Command Institutional Review Board, and in accordance with the approved protocol.

Address correspondence toBeth A. Shields, MS, RD, LD, CNSC, Clinical Dietitian, Burn Center, U.S. Army Institute of Surgical Research, 3851 Roger Brooke Drive, Fort Sam Houston, Texas 78234.

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to energy expenditure, such as fever, sepsis, surgery, and so forth. Burn patients additionally have contributing factors of burn wound, donor sites for grafting, wound infections, and healing rates. The accuracy of caloric provisions is critical, as overfeeding can lead to increased fat storage and difficulty in weaning patients off the ventilator, and underfeeding can lead to loss of lean body mass, increased infection rates, and decreased healing.

When IC is not available, our facility currently uses an equation first developed by Carlson et al[4] (Table 1) and later validated by Milner et al[5] to determine REE. However, Milner was dissatisfied with the Carlson equation in subjects 30 days after injury and concluded that IC measurements were necessary. In an attempt to refine the equation, Milner et al created their own formula (Table 1), adapted from the Carlson equation (to include an additional factor of days since injury), with which they were also not completely satisfied, as it only accounted for 40% of the variance in REE.[5] After postburn day (PBD) 30, our facility currently uses the Milner equation when IC is not available.

Dickerson et al[6] published a study in 2002 comparing the results of IC (during PBD 8 ± 5) and 46 predictive equations. They selected three formulas for their precision and decreased bias (Table 1), one of which was the Milner equation[5] (currently used at our facility after PBD 30). As the Milner equation was developed for calculation only after PBD 30, and the Carlson equation[4] was validated by Milner[5] for PBD 0 to 30, we questioned why Dickerson et al[6] found the Milner equation to be a more accurate measure of energy expenditure than the Carlson equation in the first 30 days after burn. We hypothesized that differences in practice between our center and that of Dickerson and colleagues may have led to this unexpected result. For example, the average room temperature was 74°F as reported by Dickerson et al. Maintaining room temperatures of at least 90°F is part of the routine care at our facility, as this has been found to blunt the hypermetabolic response and improve patient comfort in patients with >10% TBSA open burn wounds.[7–9] We further questioned whether differences in practice during the Carlson and Milner studies compared to current practices in our facility would result in a different selection of the most accurate predictive equation.

In a recent survey of 65 burn centers, Graves et al[10] discovered that the most commonly used formulas include the Harris-Benedict formula[11] (44%), kilocalories per kilogram (kcal/kg; 17%), followed by the Curreri formula[12] (4%; Table 1). The remaining 35% used an assortment of other formulas. We included the top three most commonly used predictive formulas in our analysis, to increase the applicability of this study to other burn centers.

The purpose of our study was to compare the accuracy of the predictive equations used at our facility along with those selected for accuracy by

Table 1. Equations for estimating daily energy expenditure for subjects with burns

Predictive Equations for Energy Expenditure
Harris-Benedict (1919)[11]
Men: $[66 + (13.7 \times WT) + (5 \times HT) - (6.8 \times Age)] \times IF \times AF$
Women: $[655 + (9.6 \times WT) + (1.8 \times HT) - (4.7 \times Age)] \times IF \times AF$
*Zawacki (1970)[18]
$1440 \times BSA$
Curreri (1972)[12]
$(25 \times WT) + (40 \times TBSA)$
Carlson (1992)[4]
$BMR \times [0.89142 + (0.01335 \times TBSA)] \times BSA \times 24 \times AF$
*Xie (1993)[17]
$(1000 \times BSA) + (25 \times TBSA)$
*Milner (1994)[5]
$[BMR \times (0.274 + 0.0079 \times TBSA - 0.004 \times PBD) + BMR] \times 24 \times BSA \times AF$

BMR, basal metabolic rate in healthy, nonburned population; *HT*, height in cm (inches/2.54); *WT*, weight in kg; *AF*, activity factor (typically 1.2–1.4); *IF*, injury factor (range of 1–2.1 used after burn).
BMR (in $kcal/m^2/hr$) as determined by the Fleisch equation (healthy population, 1951):
Men: $54.337821 - (1.19961 \times Age) + (0.02548 \times Age^2) - (0.00018 \times Age^3)$
Women: $54.74942 - (1.54884 \times Age) + (0.03580 \times Age^2) - (0.00026 \times Age^3)$
TBSA, (%) × 100 (use actual initial burn size, no cut-off for larger burns); BSA, (m^2) the square root of (HT × WT) / 3600.
*Predictive equations selected by Dickerson et al.

Dickerson et al[6] and the commonly used formulas reported by Graves et al[10] to define which formula is most accurate compared to IC during the first 30 days after burn.

METHODS

This prospective, observational study was approved by the local institutional review board. Subjects ≥18 years of age with ≥20% full-thickness TBSA burns were enrolled from October 2007 until July 2010. Subjects with electrical burns or severe head injury were excluded from this analysis.

Trained respiratory therapists and dietitians conducted IC measurements as part of routine care from PBD 0 to 30, as convenience samples. Some subjects could not be studied using IC because of claustrophobia, O_2 requirements, or inability to capture all the expired gases because of leaks in the trachea site, chest tube, or ventilator. MEE was obtained by IC early in the morning before subjects received wound care, meals, or became active. Enteral or parenteral feedings were infused continuously. MEE was obtained by respiratory gas exchange with the Vmax Encore indirect calorimeter (Sensor Medics, Yorba Linda, CA) by using a hood to capture expired gases or by connecting to the inspiratory and expiratory ports of a ventilator. The indirect calorimeter was engaged for at least 30 minutes and then calibrated before use. A mass-flow sensor was calibrated using measured volume and airflow with a certified 3-L calibration syringe, and calibration was achieved when measured stroke volume was within 3% of syringe volume. Expired gas was analyzed for O_2 concentration using a paramagnetic O_2 analyzer and for CO_2 concentration by a nondispersive infrared analyzer. Gas analyzers were calibrated before each measurement using standard gas concentrations: 16% O_2 and 4% CO_2, 26% O_2, and room air. Calibration was complete when gas analyzers measured O_2 and CO_2 concentration within 2 and 0.25% of expected value, respectively. Results were used during a steady-state period, defined by a minimum of 1 minute with a coefficient of variation <10% in volume of O_2 consumed, volume of CO_2 produced, and respiratory quotient. MEE was calculated from the results of the IC study using the abbreviated Weir equation. The abbreviated Weir equation can result in a 3 to 5% overestimation of MEE because of increased nitrogen loss with burns.[6]

Descriptive factors such as sex, burn size, age, body weight, and height were recorded from the medical record and used in the predictive equation calculations. Preinjury weight or the most recent known body weight at time of injury was used in calculating energy expenditure. Preinjury weight was provided by the subject, family, or medical or identification records. For local burns admitted within a few hours of injury, if usual weight was unknown, initial weights were measured and adjusted for the addition of resuscitative fluid minus urinary output before admission. We later questioned the subject, when able, or the subject's family members about his or her preinjury weight.

Clinically, after calculating the subject's REE using the Carlson equation[4] or performing IC, an activity factor of 1.2 to 1.4 was applied to determine total daily energy expenditure, as these factors have been found to maximize lean body mass retention and maintain weight, respectively[13]. This range for the activity factor has also been found to be appropriate by studies using isotope tracers, as total energy expenditure was equated to REE with an activity factor of 1.2 ± 0.2.[14] The goal enteral feeding rate was then based on the REE × 1.4 to account for energy expenditure of more than 95% of the population. The enteral feeding formula provided was high in protein and carbohydrate and low in fat. For subjects with >10% TBSA open burn wounds, room temperature was to be maintained at a minimum of 90°F (as long as the subject's body temperature remained <104°F) to minimize the hypermetabolic response and provide a comfortable environment for the subject.[7–9] Room temperature was recorded at the time of each IC study in the intensive care unit.

For this study, REE was predicted by using nine predictive equations including 30 kcal/kg, 35 kcal/kg, 40 kcal/kg, the Harris-Benedict equation multiplied by an injury factor of 1.5,[15,16] the Carlson equation[4], the Milner equation[5], the Xie equation[17], the Zawacki equation[18], and the Curreri equation.[12] Table 1 outlines the Carlson, Milner, Xie, Zawacki, Curreri, and Harris-Benedict equations. For all predictive equations that included burn size, the actual total %TBSA burn was used (no maximum value). An activity factor was not used in the calculations, as we were comparing predicted vs measured *resting* levels of energy expenditure. When the equation for total energy expenditure did not include a separate activity factor, the results were divided by a factor of 1.4 to determine the estimated REE.

The IC results for each subject from PBD 0 to 30 were used to determine the relationships between MEE and REE. When more than one test per subject was present, results were averaged to avoid skewing by individual subjects. Descriptive statistics including age, height, weight, BSA, %TBSA burn, PBD,

and room temperature were expressed as median and range and interquartile range. Sex and obesity were expressed as percentages.

Burn size, age, height, weight, and room temperature were compared with MEE using linear regression to determine the contribution of each to the variability of MEE and were reported as R-squared (R^2) statistic.

MEE was graphed with the predicted REE for each formula to show the relationships. The MEE and the predicted REE for each subject were described as the mean and SD. MEE vs predicted REE was evaluated by *t*-test, with $P < .05$ considered significantly different. Correlation analysis and orthogonal regression assessed relationships between MEE and predicted REE, and R^2, slopes, and intercepts were reported for each method. As there is error associated with both MEE and predicted REE, Fisher's Z-test was conducted to determine whether there was a significant difference between the different predictive equation results using *t*-values, with 1.96 considered significant.

The difference between the predicted REE and the MEE for each subject were described as the mean, SD, and range. Slope and intercept of the plotted MEE and predicted REE were compared to the line of identity. The mean differences between the predicted REE and the MEE for each subject were described using *P* values. The subjects were split into groups by burn size, and the mean differences between the predicted REE and the MEE for each subject were again described using *P* values. No correction for nonindependence was made. These analyses were conducted with Microsoft Excel 2007 (Microsoft, Redmond, WA) and SAS version 9.2 (StataCorp, College Station, TX).

RESULTS

During the study period, 120 patients were admitted to our burn center with ≥20% TBSA full-thickness burns. Thirty-one subjects with a mean age of 46 ± 19 years and a mean burn size of 48 ± 21% TBSA burns received IC studies during PBD 0 to 30, with eight subjects receiving more than one IC study during this study period. Room temperatures at the time of IC were 85 ± 5°F. Descriptive statistics on this population are shown in Table 2. The average IC study measurement was 2524 ± 738 kcal.

The correlation of MEE to descriptive factors is presented in Table 3. Burn size was the largest contributor to MEE, followed by age during PBD 0 to 30. Burn size, height, and usual body weight had a positive relationship with MEE, but age and room temperature had a negative relationship. Burn size, age, and height had moderate correlations with MEE; preinjury weight and room temperature had weak correlations.

The Milner[5] and Carlson[4] equations along with the Harris-Benedict equation[11] with an injury factor of 1.5 were the only equations with results that were not significantly different from MEE (*P* of .52, .36, and .62, respectively). The Curreri[12] equation also had a mean error that was not significant. Plots of predicted REE vs MEE are shown in Figure 1. Although it is more difficult to visually discern with the Milner and Carlson equations, all equations had slopes and intercepts that were significantly different from the line of identity when compared with MEE (Table 4). We found a calorie-dependent bias for all equations, in that the lower range was overestimated and the higher range was underestimated. Although the Milner equation results were not significantly different from MEE and showed the strongest association with the highest R^2 value and had the smallest mean error (55 ± 474 kcal), the range in error was still quite large, with underprediction of 922 kcal (75% of MEE) to an overprediction of 1342 kcal (209% of MEE), as was the error with all equations (Table 5).

Table 2. Subject characteristics (n = 31)

Characteristic	Median	Range	IQR
Age (yr)	47	19–85	23
%TBSA burn	46	20–95	24
Height (in)	69	60–74	4
Preinjury weight (kg)	73	57–112	14
BSA (m²)	1.9	1.6–2.4	0.2
Room temperature at time of IC study (°F)	85	79–97	6
PBD at time of IC study	13	4–29	11

IQR, interquartile range; *IC*, indirect calorimetry; *PBD*, postburn day; *BMI*, body mass index.
Women, 23%.
Obesity (BMI ≥ 30), 16%.

Table 3. Subject characteristics related to MEE during PBD 0 to 30

Characteristic	R^2
% TBSA burn	.45
Age (yr)	.23
Height (in)	.15
Preinjury weight (kg)	.06
Room temperature (°F)	.03

MEE, measured energy expenditure; *PBD,* postburn day.

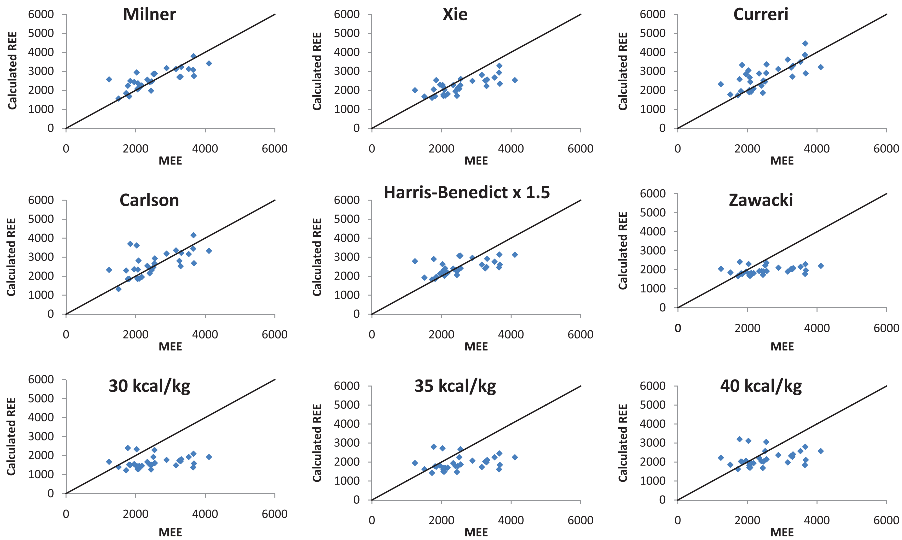

Figure 1. Predicted REE vs MEE during PBD 0 to 30. *REE*, resting energy expenditure; *MEE*, measured resting energy expenditure; *PBD*, postburn day.

Analysis of predicted REE vs MEE during PBD 0 to 30 is shown in Table 4. Milner's equation[5] had the strongest association when compared to MEE as it had the highest R^2 value, although the results of the Milner,[5] Carlson,[4] Xie,[17] Curreri,[12] and Harris-Benedict[11] × 1.5 equations were not significantly different from each other as shown by Fisher's Z-test. Fisher's Z-test did show a significant difference between the Milner equation results and the results from the kilocalories per kilogram equations and the Zawacki[18] equation.

Mean difference (error) between predicted REE and MEE during PBD 0 to 30 and the range of errors for all of the predictive equations are reported in Table 5. The mean difference was not significant with the Milner,[5] Curreri,[12] Carlson,[4] and Harris-Benedict[11] × 1.5 equations. The Curreri and Harris-Benedict 1.5 equations had mean differences that were significant in the larger burns (Table 6). Only the Carlson and Milner equations had mean differences that were not significant in all burn size groups.

Discussion

MEE in severely burned adults was compared with estimated values derived from nine equations used for the prediction of caloric expenditure during PBD 0 to 30. The Milner,[5] Carlson,[4] and Harris-Benedict[11] equation results were not significantly different from MEE, and they produced a nonsignificant mean error, but the slopes and intercepts using orthogonal

Table 4. Comparison of predicted REE and MEE during PBD 0 to 30

Equation	Mean ± SD	R^2	Slope of the Difference	Intercept of the Difference
Indirect calorimetry	2524 ± 738			
Milner	2579 ± 524*	.59	−0.5	−268
Xie†	2216 ± 417	.52	−0.6	−302
Curreri†	2736 ± 676	.48	−0.4	459
Carlson	2627 ± 662*	.38	−0.4	719
Harris-Benedict × 1.5	2468 ± 393*	.29	−0.7	−1732
Zawacki†	1966 ± 210	.11	−0.9	253
30 kcal/kg†	1649 ± 315	.06	−0.9	1576
35 kcal/kg†	1924 ± 367	.06	−0.9	1575
40 kcal/kg†	2199 ± 420	.06	−0.9	1575

REE, resting energy expenditure; *MEE*, measured energy expenditure; *PBD*, postburn day.

* *P* values not significantly different from indirect calorimetry results.

†These equations were adjusted for activity factor of 1.4, other formulas included an activity factor, which was not used in determining resting energy expenditure.

Table 5. Error of predicted REE and MEE from PBD 0 to 30

Equation	Mean Error	Range
Milner	+55 ± 474*	−922 to +1342
Xie	+308 ± 524	−1574 to +768
Curreri	+211 ± 558*	−889 to +1490
Carlson	+103 ± 616*	−999 to +1851
Harris-Benedict × 1.5	−56 ± 618*	−1197 to +1552
Zawacki	−558 ± 697	−1911 to +811
30 kcal/kg	−875 ± 727	−2272 to +625
35 kcal/kg	−600 ± 739	−2042 to +1025
40 kcal/kg	−325 ± 754	−1811 to +1425

REE, resting energy expenditure; *MEE*, measured energy expenditure; *PBD*, postburn day.
* *P* values not significant.

regression of all equations examined were significantly different from the line of identity. Because of this error at the higher and lower kilocalorie ranges, we examined each equation by burn size groups. We found that only the Carlson and Milner equations had nonsignificant mean errors in each burn size group. We agree with Dickerson et al[6] that energy expenditure cannot be precisely predicted with available methods, but, of the equations available, we recommend using the Carlson and Milner equations.

Dickerson et al[6] evaluated 46 methods of estimating REE in burn patients and noted that energy expenditure could not be precisely predicted. However, they noted that the formulas developed by Milner,[5] Zawacki,[18] and Xie[17] were the most precise. In the present study, we found the Xie and Zawacki equations to be significantly different from MEE by *t*-test and mean difference. However, the Milner equation results were not significantly different from the results of the Xie and Zawacki equations.

Although Milner et al[5] validated the Carlson[4] equation for PBD 0 to 30 and created their own equation with adjustment for use after PBD 30, this adjustment resulted in improved correlation between MEE and REE (Table 4) during PBD 0 to 30 in the present study population. Both our study and the Dickerson et al study[6] selected the Milner equation[5] as one of the most accurate. Our results, in addition, validate the use of the Milner equation[5] as one of the best equations for the first 30 days after thermal injury, although none of the equations were without serious error.

Graves et al[10] discovered that the most commonly used formulas include the Harris-Benedict[11] equation (44%), kilocalories per kilogram (17%), followed by the Curreri[12] equation (4%). The remaining 35% used an assortment of other equations. We found the Harris-Benedict × 1.5 equation to be one of the most accurate of the commonly used formulas, as the results were not significantly different from MEE, and although the R^2 value was less than that of the Milner[5] and Carlson[4] equations, the results were not significantly different from the results of the Milner and Carlson equations. Although this study had more subjects than 85% of studies to date,[6] R^2 values of 0.59 and 0.29 not having a significant difference shows that the power of the study may be the confounding factor. The Harris-Benedict × 1.5 equation had overall results of mean differences not being significant, but in the largest burn size group, there was a significant difference. The equations using only kilocalories per kilogram fared poorly in our analysis. The Curreri formula results were significantly different from MEE, with the R^2 value less than that of the Milner equation, although the results were not significantly different from the results of the Milner and Carlson equations. The Curreri equation had overall results of mean differences not being significant, but with the largest burn size group, there was a significant difference.

The Milner equation[5] was originally developed in a population of severely burned subjects and accounts

Table 6. Mean difference *P* values of predicted REE and MEE from PBD 0 to 30

Equation	All Subjects n = 31	0 to 32% TBSA Burn n = 9	33 to 65% TBSA Burn n = 16	66 to 100% TBSA Burn n = 6
Milner	0.52*	0.54*	0.65*	0.94*
Xie	<0.01	0.06*	0.03	0.31*
Curreri	0.43*	0.89*	0.29*	0.04
Carlson	0.36*	0.74*	0.70*	0.28*
Harris-Benedict × 1.5	0.62*	0.10*	0.70*	0.04
Zawacki	<0.01	0.43*	<0.01	0.01
30 kcal/kg	<0.01	0.03	<0.01	<0.01
35 kcal/kg	<0.01	0.31*	0.01	0.01
40 kcal/kg	0.02	0.77*	0.09*	0.03

REE, resting energy expenditure; *MEE*, measured energy expenditure; *PBD*, postburn day
* *P* values not significant.

for the subject's body size as well as burn size. Of the descriptive factors currently incorporated in predictive equations, burn size is the largest contributor to the REE. Equations that included burn size followed the line of identity more closely than those that did not. The R^2 for burn size alone when compared with MEE was higher than six of the nine predictive equations examined. Burn size and age had the strongest correlation with IC measurements. Only the Carlson and Milner equations included both burn size and age. Height and weight had minimal contribution to REE ($R^2 = 0.15$ and 0.06, respectively) and were commonly the only demographic data in calculations for energy expenditure. Room temperature also had a minimal contribution to REE in this study, but this may be because of the room temperature being adjusted for metabolic stability, and therefore the metabolism was minimized. Other factors, such as healing, donor site area, sepsis,[13] and caloric provisions[19] would likely be required in future predictive equations to improve the calculations for REE. This study was exploratory in nature, not designed to be a definitive answer as to which equation must be used, eliminating all other equations. Future research should focus on additional factors with a larger sample size.

Limitations to this study include only examining the first 30 days after burn. Trending of individual subjects over time might aid in determination of which equations are most accurate after this time period. Only seven women were enrolled in this study; therefore, risk for sex-related errors were present. Large errors in predicted REE occurred with each equation. It was unclear whether the MEE or the predicted REE would have provided the best clinical outcome due to subsequent prescription of nutritional support. Thus, we are still far from arriving at the perfect formula to accurately predict energy use in the severely burned. These determinations could also arise with testing of clinical outcomes (survival, healing time, retention of lean body mass) in comparison to energy provided and energy expenditure. Further research will help clarify desired caloric levels.

The goal of this study was to assess the accuracy of nine predictive equations for calculating REE. On the basis of the results, the Milner and Carlson equations are the most satisfactory methods to estimate the REE for the first 30 days after injury in the severely burned when IC is not available.

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